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Urban Heat Island of Lincoln, Nebraska

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URBAN HEAT ISLAND OF LINCOLN, NEBRASKA

By

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URBAN HEAT ISLAND OF LINCOLN NEBRASKA

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Abstract

The purpose of this research was to prove Lincoln Nebraska is an urban heat island, and temperatures within canopy are on average warmer than outside of canopy. This research is important because an urban heat leads to negative impacts on the human health, higher energy costs are evident, and has detrimental effects on aquatic ecosystems. In the study, temperatures under canopy and outside of canopy were recorded both in the dense urban area of Lincoln, as well as its rural counterpart 10.9 miles from the city center at Deer Springs Winery. The temperatures were then graphed to analyze the differences. The four months of data showed that canopy temperatures inside Lincoln were 1-4 ^{o}F warmer and no canopy temperatures in the city were 2-5 ^{o}F warmer, making Lincoln an urban heat island. Longer than 4 months of data across multiple seasons would improve the credibility and accuracy of the data along with better technology, such as remote sensing.

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Background

An urban heat island (UHI) is the concept that impervious surfaces attract large amounts of heat, leading to higher temperatures in urban areas compared to their rural counterpart (US EPA, Heat Island Impacts, 2016). This problem is a growing concern across the world as urbanization, urban sprawl, and the number of people living within cities continues to increase. Studies project that by 2050, 70% of the population will live in urban areas and the developed cities of 100,000+ people will nearly multiply the area of impervious surfaces by 2.5x (Tzavali et al., 2015). More buildings lead to more impervious services, which attracts heat, especially during the warmer months of the year. Along with higher daytime temperatures, at night, the impervious services release the heat resulting in a much warmer nighttime temperature within the city compared to its rural counterpart. This study hypothesizes that temperatures within cities are overall warmer than their rural counterpart, and the difference in temperatures is greater outside of canopy (shade/trees). The three main aspects looked at in terms of the UHI is: how drastic the differences in temperatures are, what the temperature changes are compared to the amount of impervious surface (urban vs rural), and how the amount of canopy provided from trees affects the UHI. Some of the literature reviewed looks at areas that have similar climates to that of Lincoln, and others that are very dissimilar to Lincoln. Also, some of the cities are in comparable size to Lincoln, while others are much larger.

Prior to conducting research, it was important to take into consideration where the UHI is the greatest in regards to differences outside of the canopy and the placement of temperature loggers for the most accurate results. It was also paramount to find a heavily canopied area to analyze how the temperatures compare to the areas with little or no canopy. Overall, distinguishing where urban heat islands are located is important in minimizing cooling costs, helping to bring awareness to heat related illnesses in cities, and lastly preventing negative impacts on aquatic ecosystems. For example, a direct relationship has been found between UHI, heat-related illness and fatalities, due to the incidence of thermal discomfort on the human cardiovascular and respiratory systems (Luber & McGeehin 2008). In terms of the ecosystem impacts, due to urban sprawl, impervious surfaces and UHI have become a key issue due to the impact that it has on habitat health (Cithra et al., 2015).

Literature Review

Some of the previous research conducted in the United States involved case studies completed in Chicago IL, Madison WI, Indianapolis, IN, and Oklahoma City, OK. The research primarily included finding the heat islands and determining their magnitude. These cities all have similar climatic conditions to Lincoln, with Madison being similar in size, and Chicago and Indianapolis being highly populated dense cities and similar climate. Oklahoma City is slightly unique in that the population is like Lincoln, however, vegetation and climate is marginally different.

Studies within Chicago indicate that the UHI was present within the city, but the wind also had an effect on temperatures. “The Windy City” is known for receiving summer winds off of Lake Michigan, which has large impacts on the climate. The study analyzed data from both Chicago O’Hare airport and Chicago Midway Airport for an extended period of time. O’hare is further from the city center and Midway is closer, meaning temperature data should be different between the airports. The data determined that Midway’s average August 2013 temperature was 0.5 ^{o}C (~1 ^{o}F) higher than O’Hare with the average minimum temperature being 1.2 ^{o}C (~2 ^{o}F) higher (Conry et al., 2015). They were able to see how at night when the impervious surfaces began to release the heat absorbed during the day, and the breeze from Lake Michigan began to lessen, the UHI magnitude was enhanced. They estimate that in the near future, August temperatures in downtown Chicago could be up to 4.5 ^{o}C (~ 8 ^{o}F) higher than they are now because of the sprawling city (Conry et al., 2015).

In central Indiana, Rajasekar & Weng selected nine counties to test the patterns of where and how large UHI’s were. They used Marion County, which is the highest populated county in Indiana, and then chose eight counties in the surrounding area with a lower population (Rajasekar & Weng, 2009). They tested many variables throughout this study, but one that is relevant to this study, was the temperature difference between urban and rural areas. The research showed that there was a 1-5 ^{o}C (~ 2–9 ^{o}F) difference for daytime temperatures from Marion County to its surrounding areas, and 1-3 ^{o}C (~ 2-5 ^{o}F) difference for nighttime temperatures (Rajasekar & Weng, 2009). Like Chicago, Indianapolis has a similar climate to Lincoln, but does have a higher population.

Basara et al focused their research in July and August of 2008 when a strong heat wave came through the city. This city is known for having very warm temperatures in the summer, and due to little rainfall, vegetation is less prevalent compared to other cities studied. Their research indicated that nighttime temperatures in urban Oklahoma City were about 3 ^{o}C (~ 5 ^{o}F) warmer compared to ones in the rural areas around (Basara et al., 2010). They determined that this was a result of anthropogenic heating, increased impervious surfaces, rural areas cooled off quicker, and decreased sky view within a city (Basara et al., 2010). During this time period, some Oklahoma City urban residents experienced more heat related illnesses than residents in rural areas due to both the heat wave and the UHI (Basara et al., 2010).

The study in Madison, WI was done over an 18-month period from April 2012 to September of 2013. Their goal was to show the differences in UHI's between seasons. Their overall findings indicated that the UHI's are more intense during warmer summer months and lower during the winter months when the sun's energy wasn't as intense (Schatz & Kucharik, 2014). The month of September, in particular, yielded the biggest differences between nighttime and daytime temperatures compared to the rest of the months. This in depth search even looked at wind speeds:

> "Seasonal trends in monthly average wind speed and cloud cover tracked annual trends in UHI intensity, with clearer, calmer conditions that are conducive to the stronger UHIs being more common during the summer" (Schatz & Kucharik, 2014).

Findings indicated that summer nights without wind or clouds had a created a more significant UHI than the same conditions during winter nights due to vegetation and snow cover in their respected months (Schatz & Kucharik, 2014). The authors determined that snow cover and vegetation were responsible for season baselines for UHI intensity, but daily occurrences such as wind, clouds, precipitation, etc. resulted in daily UHI intensities (Schatz & Kucharik, 2014).

Another study conducted research about UHI's on the 50 most populous states across the United States. A quick synopsis of the results indicated that the fifty states were on average 0.37 ^{o}C (~ 1 ^{o}F) warmer than the undisturbed environments around them (Debbage & Shepherd, 2015). They determined that Salt Lake City had the highest magnitude UHI at 1.49 ^{o}C (~ 2.5 ^{o}F) due to temperature inversions producing calm, clear & stable conditions for a UHI (Debbage & Shepherd, 2015).

The second city observed was Miami, FL at 1.34^{o}C (~ 2.5 ^{o}F) due to tall skyscrapers preventing the sea breeze from entering the city, and lastly was Louisville, KY at 1.12 ^{o}C (~ 2 ^{o}F) because of absence of seasonality, and the absence of a tree ordnance resulting in lack of canopy (Debbage & Shepherd, 2015). The inaccuracy within this experiment was the fact this data set did not exclude cloudy/gloomy days. Gloomy and cloudy days tend to yield very similar conditions within the urban area as well as in the rural area. This could potentially be a limitation of the data. Looking deeper into how these scientists conducted their research may provide ideas on what to do with this experiment. The data should end up looking similar to theirs, especially Schatz & Kucharik's data, if done correctly, as both climates have similarities in temperatures.

The previous examples analyzed cities in the United States, which is adequate for the purpose of this study. However, there have been multiple studies in Asia that have proved the UHI's can take place at even larger scales. For example, in Beijing, Landsat/TM satellite imagery was used to measure near surface UHI effect within the city. Beijing is a city that can get very warm in the summer with temperatures reaching 30 ^{o}C (80 ^{o}F) (Xu & Liu, 2015). The population of the city is over 20 million living in this urban area. This, in effect, means that buildings are densely distributed, and there is little room for vegetation. The studies found that between the urban area and its rural counterpart, there were large differences in the temperatures. "The temperatures of the western and northern mountains were typically below 28 ^{o}C (~ 83 ^{o}F) and the temperature typically exceeded 32 ^oC (~ 90 ^oF) in the urban areas" (Xu & Liu, 2015). Other cities that have highly intensive UHI's include Tokyo, Shanghai and Bangkok.

Xu and Liu (2015) found that "when the impervious surface coverage was below 40 percent, the temperature increased rapidly with increasing impervious surface coverage, and when the impervious surface coverage was above 40 per cent, the temperature increased slowly".

The authors are implying that impervious surfaces are directly related to temperature increase, and to mitigate this problem, cities need to cover impervious surfaces with vegetation, decrease building density, increase green roofs, and increase bodies of water (Xu & Liu, 2015).

Effects of the Urban Heat Island

The above research suggests that in many cases, cities are warmer than their rural counterpart. What does this mean? What are the impacts? Why should the public care? Many of the effects lie within environmental justice issues as well as environmental impact.

Low-income people are most often associated with living in densely populated areas with less access to proper cooling (Mitchell & Chakraborty, 2014). A prime example is Chicago back in the mid 1990's. A prolonged heat wave struck the city killing over 500 people. Most of them were low income residents that could not afford air conditioning and were not residing in properly insulated homes. The UHI in the city made conditions even worse with nighttime temperatures not decreasing enough to cool the homes (Mitchell & Chakraborty, 2014). These events aren't just a one-time occurrence. Each summer across many cities there are heat waves that impact cities, resulting in casualties.

In the Clearwater/St. Petersburg area of Florida, the low-income are faced with the same issue, but in a different way. The beachfront is where all the resorts, hotels, and higher income residents stay and live. Along the beach is one of the few areas where the sea breeze is strong enough to decrease temperatures within the city. Behind the buildings is most often where low-income people live in part to the less desirable view and cheaper living (Mitchell & Chakraborty, 2014). The buildings in turn end up blocking the breeze from reaching these resident areas, making it much warmer.

The EPA has compiled a list of issues that warmer temperatures in the city create. One of the largest impacts is increased energy consumption (EPA, 2016). A study suggested that for every 1 ^{o}F increase, electricity demand for cooling increases 1.5-2.0% (Akbari, 2005). This eventually can lead to blackouts in the late afternoon when offices are using electricity for light as well as cooling their large buildings. Many of our large scale electrical plants are powered by fossil fuels, therefore, with increased energy demand comes increased greenhouse gas emissions such as sulfur dioxide, nitrogen oxides, carbon monoxide, etc. Human health and comfort was mentioned earlier in the case of Chicago and Oklahoma City, but another impact is water quality. A study suggested when pavement reaches 100 ^{o}F, it can elevate the temperature of rainfall that is at 70 ^{o}F to over 95 ^{o}F when it hits the pavement and runs off (James, 2002). This extremely warm water runoff drains into lakes, ponds, rivers, etc, raising the temperature of these bodies of water. Increased water temperatures as we know are occurring throughout the planet, having severe impacts on aquatic ecosystems.

One way of decreasing the urban heat island effect is to increase the amount of canopy within a city. Having an abundance of trees within a city and preventing the sun from reaching impervious surfaces is an easy and effective way to avoid the UHI's, which as previously stated, has human impacts. Trees within cities are good for all of the obvious reasons. Trees are a good source of shade around buildings and on surfaces that may reflect solar radiation onto buildings. Lastly, they reduce the amount of heat being absorbed by the building, resulting in less pollution which is directly correlated with higher energy consumption (Loughner et al., 2012). A summertime energy study was conducted, and scientists transported eight 6-meter tall trees, and eight 2.4-meter tall trees around a house and measured their energy consumption to find out that they helped decreased energy demand by approximately 30% throughout the summer (Donovan & Butry, 2009).

More trees also have a beneficial impact on the air quality within a city by decreasing carbon dioxide levels in the atmosphere. One study suggested that if Los Angeles planted approximately 20 million trees in their air basin, they would help reduce the weight of ozone in the mixed layer by about 4.5% due to increased ozone deposits and nitrogen dioxide" (Loughner et al., 2012).

Out of all these topics, this study will focus on simply the differences in temperature, along with an illustration on the effect of urban canopy. Conducted in the city of Lincoln, NE, this study will provide evidence whether the urban heat island effect is present or not in the city. If this data can prove that Lincoln does have an urban heat island effect, and that providing trees would make a difference, the evidence could prompt cities to plant more trees to counteract this issue. That results of this analysis will also be compared to similar cities such as Madison WI, Chicago IL, or Indianapolis IN.

Materials & Methods

The methods for this study were simple. On May 27th, five WatchDog 2450 Mini Station Temperature loggers were set up within Lincoln and just outside of the city. The two temperature loggers outside of the city were placed on fence posts, one being in complete sunlight, the other in as complete shade as possible. The locations for the temperature loggers were:

1) In a tree (13th & N Street, high urbanization with canopy)
2) Rooftop of Firestone Complete Auto Care (11th & N Street high urbanization, no canopy)
3) Deer Springs Winery (162nd & Adams Street in a meadow, no canopy)
4) Deer Springs Winery (In a bush/tree, canopy)

Figure 1 (see Appendix) shows these locations on a map. The rural locations are approximately 10.9 miles away from the urban downtown locations. The landscape surrounding Locations 3 and 4 is completely rural with vegetation from crops to grass, to trees.

The study was set up similar to the way Rajasekar & Wang 2009 set up their experiment, in that they measured temperature within downtown Indianapolis, and also in the 8 rural counties that surrounded the city. Due to fewer resources, the experiment was constructed at a smaller scale with only 2 locations being in the city, and 2 outside of the city in an urban area, but still in the same county.

These temperature loggers logged the temperature, humidity, dew point, and the photosynthetically active radiation (PAR) once every 30 minutes. For the purpose of this study, only the temperature was analyzed at each hour. The data collection ended on September 27th, 2016. This resulted in 4 months of data with temperatures ranging from cooler spring and late summer temperatures, to warm mid-summer temperatures. Once the 4 months of data collection was finished, the temperature data was graphed to analyze the differences. The hourly temperature only allows one to see which times the warmest and coolest temperatures occurred at throughout each day.

After analyzing which times of the day normally yielded the lowest/highest temperatures, a decision was made to use the readings at 7:00 AM and 5:00 PM (1700 hours) for every graph constructed to ensure the times were consistent throughout. The warmest and coldest average calendar weeks was chosen of the data sets. The warmest was June 12-18th and the coldest was September 11th-17th. There were six total bar graphs constructed for this part of the experiment.

The weeks within the data was then analyzed and searched for outliers, or days that weren't consistent with the rest of the data. For the coldest week in the data set, there happened to be two consecutive days where low/high and 7:00AM/5:00PM temperatures were nearly identical. This was due to a weather system that left cold, cloudy, and gloomy temperatures. The two days were removed (September 13th and 14th), and three more graphs were constructed with new temperature differences between urban and rural at 7:00 AM and 5:00 PM. The graphs constructed were as follows:

Figure 2. Urban vs Rural No Canopy (Warmest Week)

Figure 3. Urban vs Rural No Canopy (Coldest Week)

Figure 4. Urban vs Rural Canopy (Warmest Week)

Figure 5. Urban vs Rural Canopy (Coldest Week)

Figure 6. Urban No Canopy Vs Urban Canopy (Warmest Week)

Figure 7. Urban No Canopy Vs Urban Canopy (Coldest Week)

Figure 8. Urban vs Rural No Canopy (Coldest Week & Removal of Outliers)

Figure 9. Urban vs Rural Canopy (Coldest Week & Removal of Outliers)

Figure 10. Urban No Canopy vs Urban Canopy (Coldest Week & Removal of Outliers)

At the very end, the average temperatures across the whole 4-month data set at 7:00 AM and 5:00 PM were analyzed to see the differences and these averages were extracted and then inserted in a table (see appendix Table 1).

Results

As expected, Figure 2 (see appendix) illustrates how the largest average difference in temperature between the urban (Location 2 (L2)) and rural temperature loggers (Location 3 (L3)) came in the warmest week (95.8 ^{o}F average high) outside of canopy, with a 1.99 ^{o}F warmer 7:00 AM temperature in the city and a 5.03 ^{o}F warmer 5:00 PM temperature. These differences are located at the top right corner of each figure.

Figure 3 (see appendix) illustrates the exact same variables, except readings were taken in the coolest calendar week in the data set based, on the average high temperature for each day (77.2 ^{o}F average high). The urban temperature at 7:00 AM on average was 1.93 ^{o}F warmer than the rural temperature. This is nearly identical to the differences in temperatures in Figure 2. For 5:00 PM, the urban temperature was only on average 2.91 ^{o}F warmer compared to the rural temperature. In both cases, urban temperatures were warmer than rural, however not as significant as the warmest week of the data set, seen in Figure 2.

Figure 4 (see appendix) switches over to analyzing urban vs rural temperatures under tree cover (canopy) in the warmest calendar week of the data set. The collection method stayed consistent with only using the readings at 7:00 AM and 5:00 PM. Location 1 (L1) was the urban setting with results being 2.40 ^{o}F warmer on average at 7:00 AM compared to the rural temperature under canopy (Location 4 (L4)). At 5:00 PM the data suggests at the urban location, L1, temperatures on average were 3.59 ^{o}F warmer compared to the rural area, L4.

Figure 5 (see appendix) once again analyzed the same variables, but in the colder week of the data set. At 7:00 AM, L1, the data suggested that on average, temperatures were 1.83 ^{o}F warmer compared to the rural location, L4. At 5:00 PM, temperatures were even warmer yet, with L1 recording an average 2.36 ^{o}F warmer temperature.

Figure 6 and 7 (see appendix) were designed to look strictly at the difference between canopy and no canopy temperatures within the urban setting (Locations 1 and 2). Figure 6 analyzed temperatures within the warmest calendar week of the data set. The data suggests that at 7:00 AM on average, the temperature not under canopy (Location 2) was actually 0.34 ^{o}F colder compared to the 7:00 AM temperature under canopy (Location 1). At 5:00 PM, on average, Location 2 recorded a 1.93 ^{o}F warmer temperature in comparison to L2 at 5:00 PM.

Figure 7 looked at the difference in canopy and no canopy temperature between the two urban temperature loggers, but for the coldest calendar week of the data set. At 7:00 AM, Location 2 (no canopy) again ended up being on average -0.33 ^{o}F cooler than Location 1 within Lincoln, but by 5:00 PM, the temperature at Location 2 warmed up and on average was 1.54 ^{o}F warmer compared to Location 1.

The last three figures 8, 9 and 10 (see appendix) were graphs that did not include the outliers in the data set. If the 2 outliers (September 13th & 14th) were removed, the differences in temperatures were greater. Figure 8 demonstrates that when the outliers were removed, the urban vs rural no canopy temperature difference was on average 2.46 ^{o}F warmer in the city at 7:00 AM, and on average 3.90 ^{o}F warmer at 5:00 PM. These numbers increased slightly from the 1.93 ^{o}F difference and 2.91 ^{o}F difference in Figure 2. Figure 9 shows that with the outliers removed, the urban vs rural canopy temperature difference on average was 2.12 ^{o}F warmer in the city at 7:00 AM, and on average 2.94 ^{o}F warmer at 5:00 PM. Again, these increased slightly from the 1.83 ^{o}F difference and 2.36 ^{o}F difference in Figure 5.

Table 1 was designed to look at the differences in urban/rural and canopy/no canopy across the whole 4-month data set. There are many comparisons to be made off this table but only a few significant ones will be listed. Urban temperatures not under canopy at 7:00 AM and 5:00 PM on average were 2.98 ^{o}F and 4.24 ^{o}F warmer to their rural counterpart not under canopy, respectively. Urban temperatures under canopy at 7:00 AM and 5:00 PM on average were 3.33 ^{o}F and 3.17 ^{o}F warmer compared to their rural counterpart under canopy, respectively. The last calculation is to see whether canopy really had an effect on temperature just within in the city, Urban temperatures *not* under canopy at 7:00 AM and 5:00 PM on average were -0.49 ^{o}F and 1.92 ^{o}F warmer compared to temperatures under canopy, respectively. Note that the 7:00 AM difference says -0.49 ^{o}F warmer, indicating the temperature on average, not under canopy, at that time was cooler than the temperature under canopy.

With the data compiled, significance tests were completed to see if these differences were large enough to say there was a difference. A significance test uses the means and standard deviations of the data to see whether the hypothesis should be rejected or retained.

Discussion

In Rajasekar & Weng's experiment, which was similar to how this experiment was conducted, they explored the differences in daytime and nighttime temperatures in urban vs rural counties around the Indianapolis area. The research suggested the magnitude of the Urban Heat Island in Indianapolis was around 2 - 9 ^{o}F warmer during the day, and 2 - 6 ^{o}F warmer during the night in compared to surrounding counties (Rajasekar & Wang 2009). In comparison to the data collected in Lincoln, it appears there is a substantial difference in Indianapolis urban vs rural temperatures. The reason is most likely due to the sheer size difference between the cites. The size of Lincoln is around 90 square miles, while Indianapolis is around 370 square miles, which is over 4x the size of Lincoln. This means there are much more impervious surfaces, taller buildings, and greater chance of an UHI in Indianapolis.

After looking at all the data collected around Lincoln, it is evident that within the urban area, temperatures are warmer, however, is it warm enough to really call the city an "Urban Heat Island"? The largest difference in urban vs rural temperatures occurred at 5:00 PM, during the warmest week, and it was between the "no canopy" temperature loggers. The difference was +5.03 ^{o}F within the city. The overall range of temperature differences outside of the canopy between urban and rural was about 2 – 5 ^{o}F. The temperatures within the canopy were slightly lower with it being on average 2.91 ^{o}F warmer at 5:00 PM in the city. Returning to the hypothesis that the difference in temperatures is greater outside of the canopy, it is evident that this held true for nearly every scenario graphed. In both the warmest and coldest weeks, the difference between urban and rural canopy temperatures was slightly less, hovering between 1- 4 ^{o}F, compared to the 2 – 5 ^{o}F difference outside of canopy. Across the whole four-month data set, temperatures still ranged from around 3 ^{o}F warmer under canopy in the city, and about 4 ^{o}F warmer in the city outside of canopy. Both in the range of differences in the temperatures recorded for the warmest and coldest week.

Another variable being considered was if canopy influenced urban temperatures. It is important to focus on the 5:00 PM temperature reading for this comparison, because as stated in the methods, this is the time frame when energy consumption is elevated. On average, the temperature was about 1.5-2.0 ^{o}F warmer outside of the canopy. This isn't as drastic as expected, but according to Akbari (2005), this could increase energy costs in downtown Lincoln by about 4%.

If the 2 outliers (September 13th & 14th) were removed, the differences in temperatures were greater. Figure 8 shows how when the outliers were removed, the urban vs rural no canopy temperature difference was on average 2.46 ^{o}F warmer in the city at 7:00 AM, and on average 3.90 ^{o}F warmer on average at 5:00 PM. These numbers are both up slightly from the 1.93 ^{o}F difference and 2.91 ^{o}F difference in Figure 3. Figure 9 shows that with the outliers removed, the urban vs rural canopy temperature difference on average was 2.12 ^{o}F warmer in the city at 7:00 AM, and on average 2.94 ^{o}F warmer on average at 5:00 PM. Again, these were both elevated slightly from the 1.83 ^{o}F difference and 2.36 ^{o}F difference in Figure 4, respectively.

The last two figures that need to be explained are Figure 6 and 10, which are the comparisons of the two urban temperature stations, one within canopy and one not in canopy. In both Figure 6 and 10, the 7:00 AM canopy temperature is actually warmer than outside of canopy. This is due in part because the vegetation takes longer to warm/cool compared to the air, because water cools/warms slower than air, and the vegetation has a higher content of water build up inside of it. For example, on June 15th, at 7:00 AM the humidity under the canopy was at 68.7% with a temperature of 70.6 ^{o}F, and outside of the canopy the humidity was 66.9% with a temperature of 69.7 ^{o}F. Just this small difference in humidity has a possible effect on the slightly warmer temperature under canopy.

To see whether these differences were large enough to call Lincoln, Nebraska an urban heat island, significance tests were conducted using SAS (Statistical Analysis Software). A significance test considers all data points to see if the differences are consistent and large enough to actually be significant. The test used 95% confidence intervals (CI's), and eventually reading the P value. If the P Value was <0.05, then one can be 95% sure that there is a difference between the data. In all tests relating urban vs rural temperatures, regardless of time of day or amount of canopy, all P values were <0.0001, indicating a 95% confidence that there is an urban heat island within Lincoln, Nebraska.

The other variable tested within this study involved whether the amount of canopy influenced the local temperatures (urban vs urban and rural vs rural). Using the SAS, the results originally yielded P= 0.0549, indicating the differences between canopy and no canopy were not significant, but very close. With removing the outliers as stated above would then put the P value below 0.05, indicating that with 95% confidence, the difference between canopy and no canopy for all times is significant.

Conclusion

As stated, this study was conducted to prove whether or not Lincoln Nebraska has any evidence of an urban heat island. It can be concluded from the data collected and the significance tests, that the city does have a minor urban heat island and that temperatures outside of canopy are significantly warmer than inside canopy. For a city the size of Lincoln, one doesn't expect for the urban vs rural temperature gradient to be as large compared to cities like Indianapolis or Chicago, which was the case in the literature studied. While urban temperatures in Indianapolis tended to be 2-9 ^{o}F warmer during the day and 2-6 ^{o}F warmer during the night, Lincoln's temperatures usually hovered between 1-4 ^{o}F warmer under canopy and 2-5^{o} F warmer outside of canopy. This data was fairly consistent between both the warmest and coldest week as well as throughout the whole 4 months of data.

Future studies should examine the differences throughout all seasons and base the data collection on a full year(s) rather than four months. This would allow for analyzing the differences between seasons, and it could possibly measure if the amount of snow on the ground had an impact on temperature gradients. Another recommendation for future research is the addition of several temperature loggers to analyze how the temperatures differ from the downtown vicinity. For example, obtain 5 temperature loggers, and place them every 3 miles from the city center, eventually ending up in a rural landscape.

It is also equally important to look at doing this type of study with more precise and developed technology. For the purpose of this study conducted in terms of budget and time allotted, simple temperature loggers were the only option. In many of the studies cited in the literature review, remote sensing (or the use of satellites) was used to look at temperatures across a much larger area. Remote sensing would allow for one to see temperatures and hotspots across the whole city of Lincoln, and the rural area instead of just specific locations.

Urban heat island has been to blame for hundreds of heat related deaths, higher consumption of energy to cool buildings, and damaging effects on aquatic ecosystems due warm runoff. With 8 billion people on the horizon, urban areas becoming denser, and cities across the world continuing to grow, the problems explained in this study are increasing and significant to the well-being of communities. With temperatures increasing, and affecting aquatic life, UHI is also particularly stressful and detrimental to aquatic ecosystems. This research and further research may aid in bringing awareness to these problems and will prompt urban planners to take proper action steps to combat these issues.

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Appendix A

Figures & Tables

Figure 1. Locations of Temperature Loggers

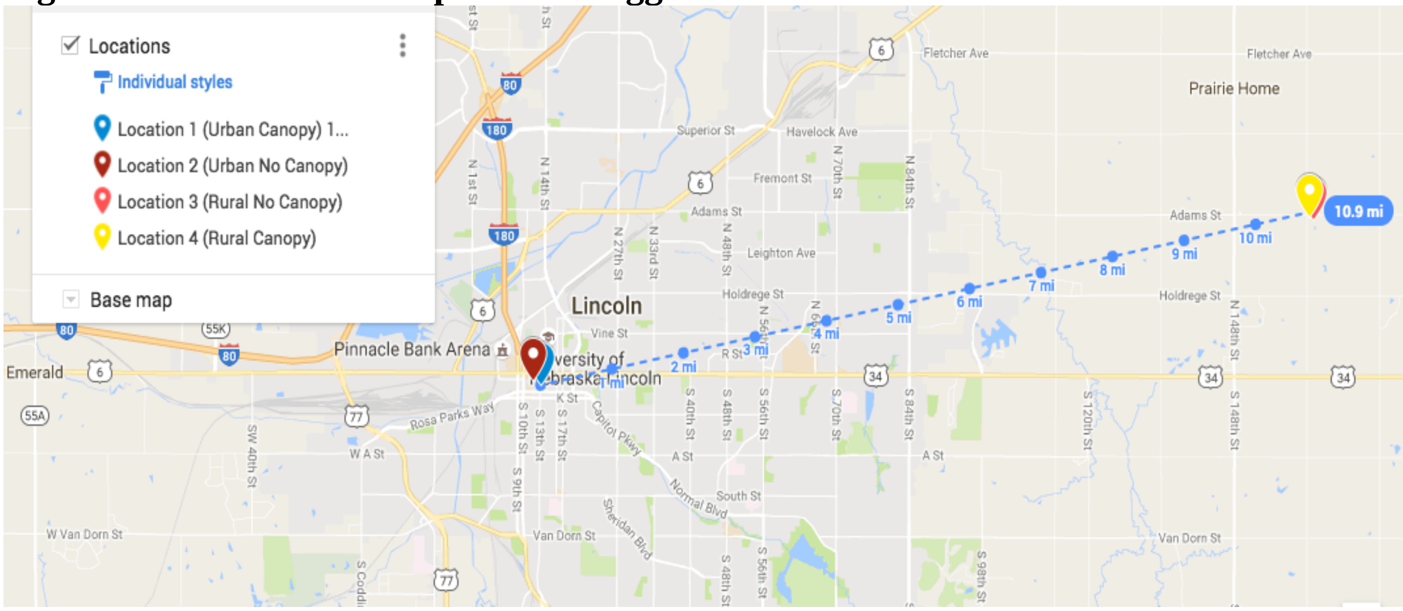

Figure 2. Urban vs Rural No Canopy Temperatures (Warmest Week)

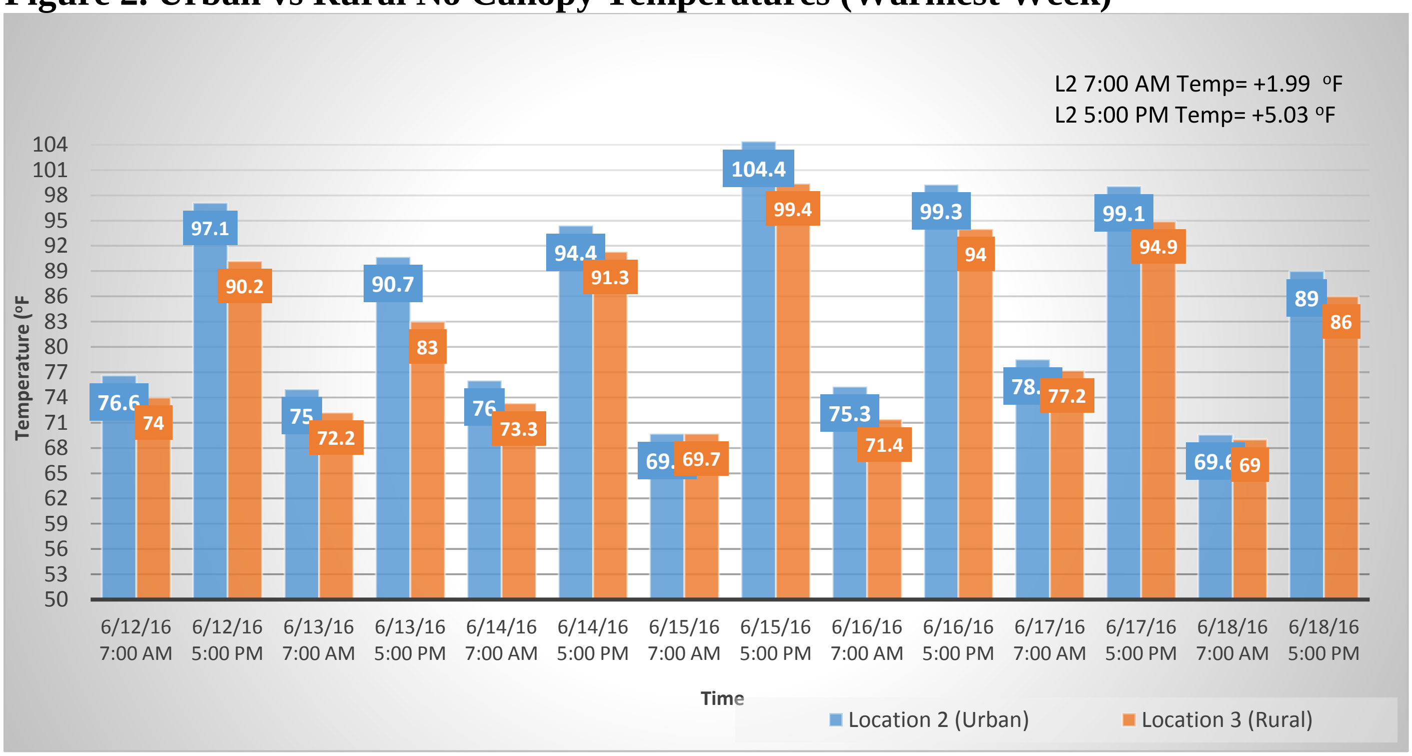

Figure 3. Urban vs Rural No Canopy Temperatures (Coldest Week)

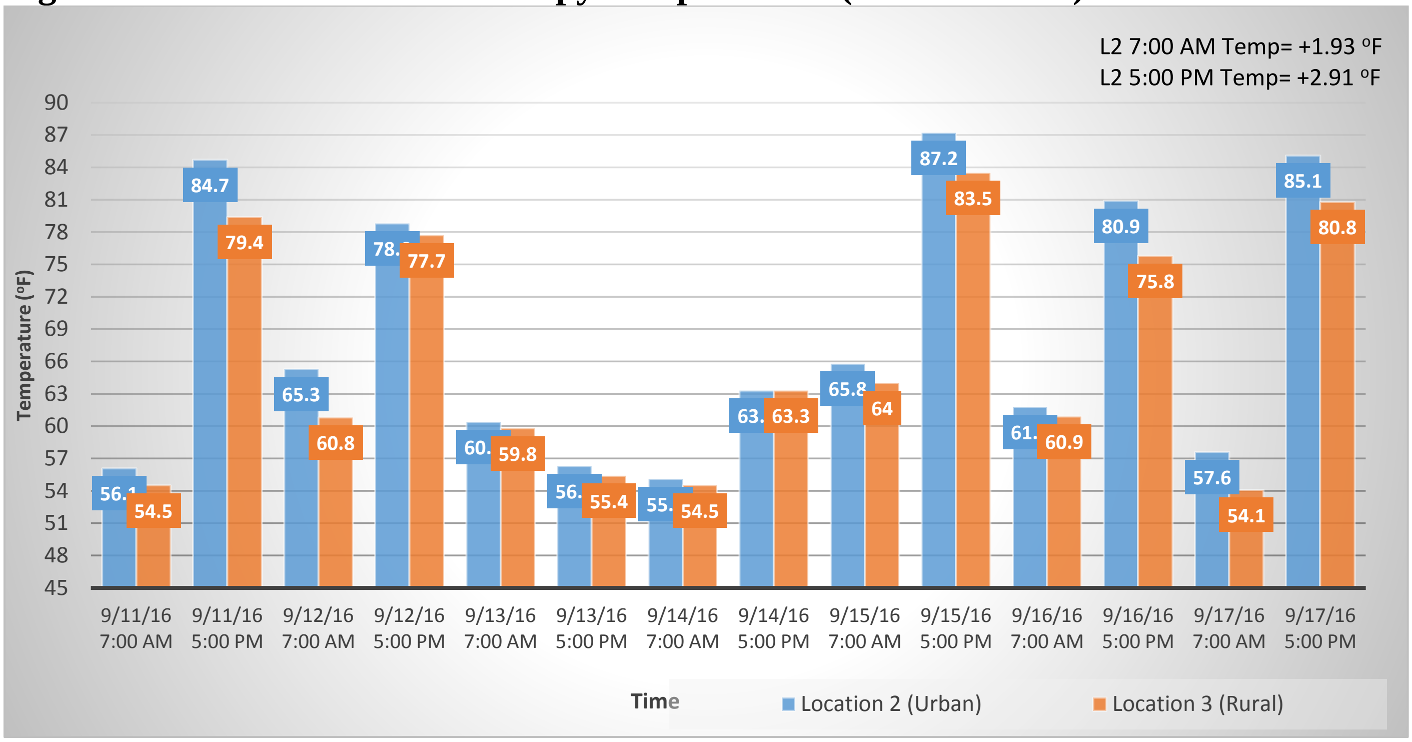

Figure 4. Urban vs Rural Canopy Temperatures (Warmest Week)

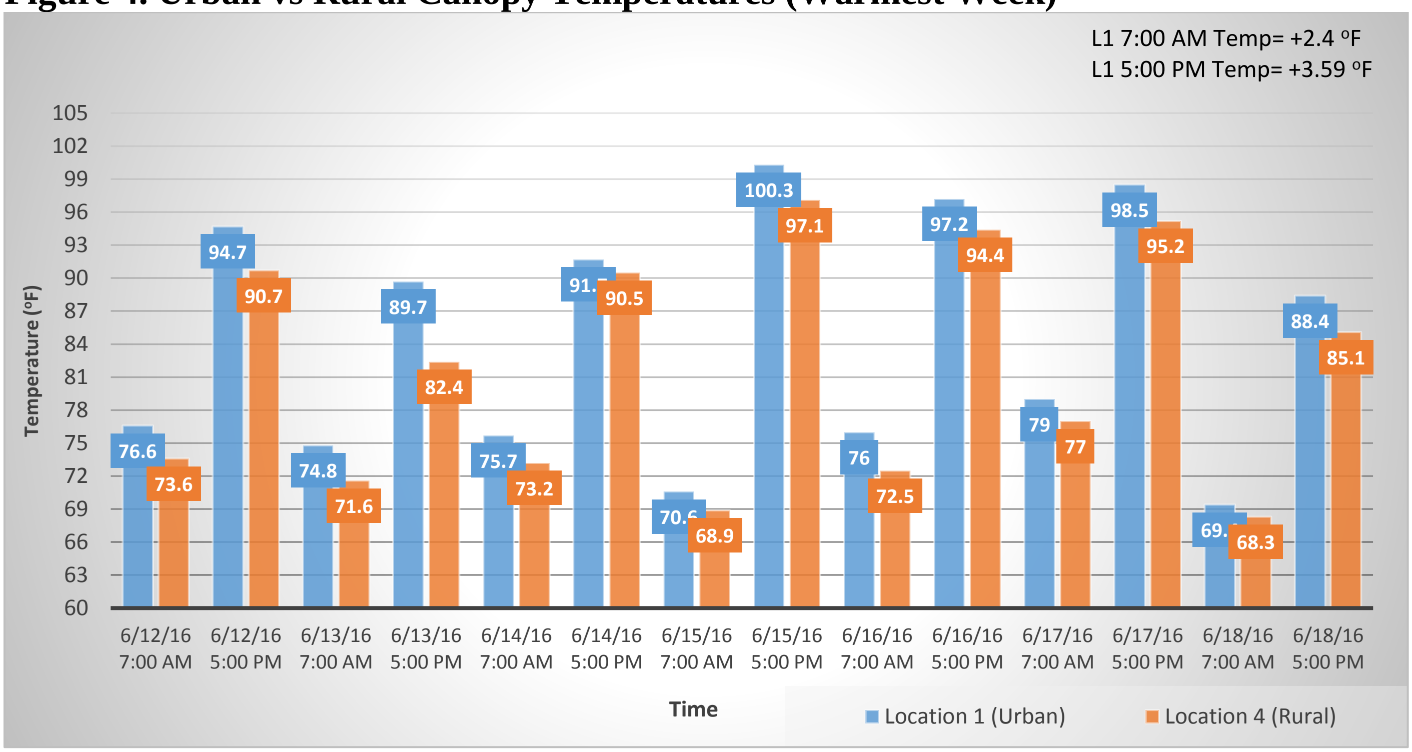

Figure 5: Urban vs Rural Canopy Temperatures (Coldest Week)

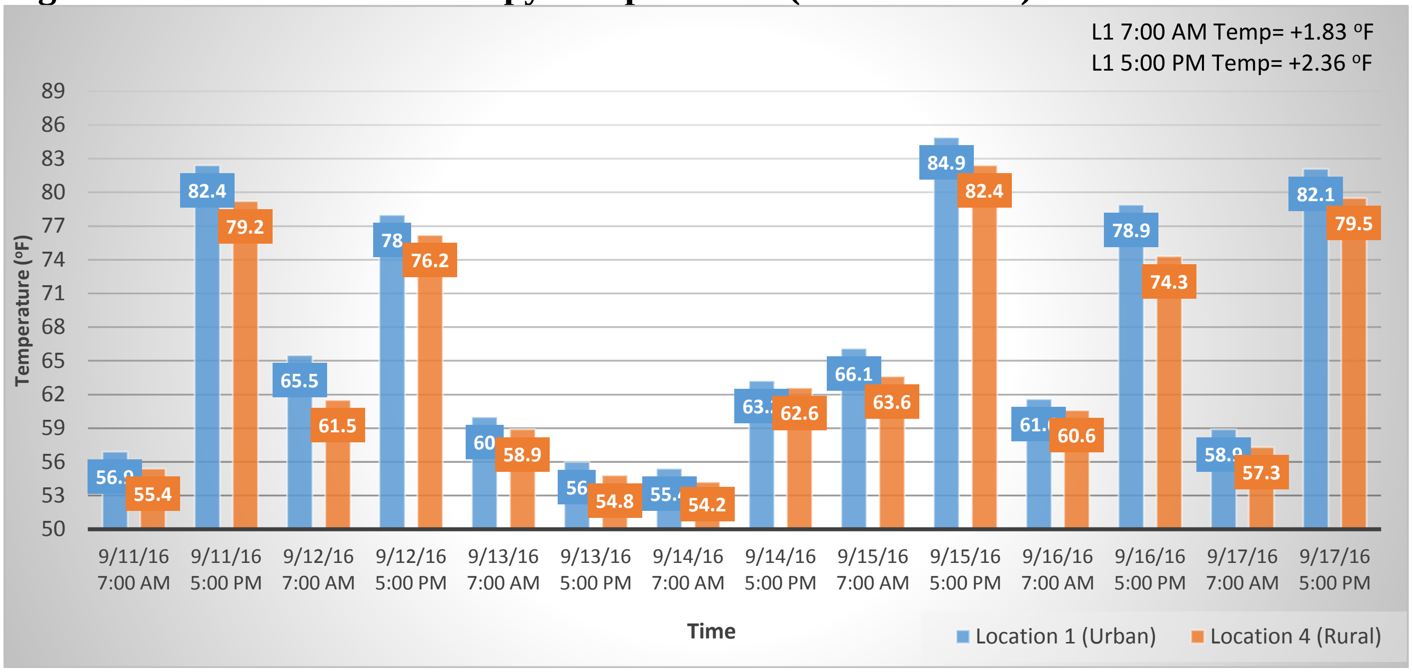

Figure 6: Urban vs Urban No Canopy/Canopy (Warmest Week)

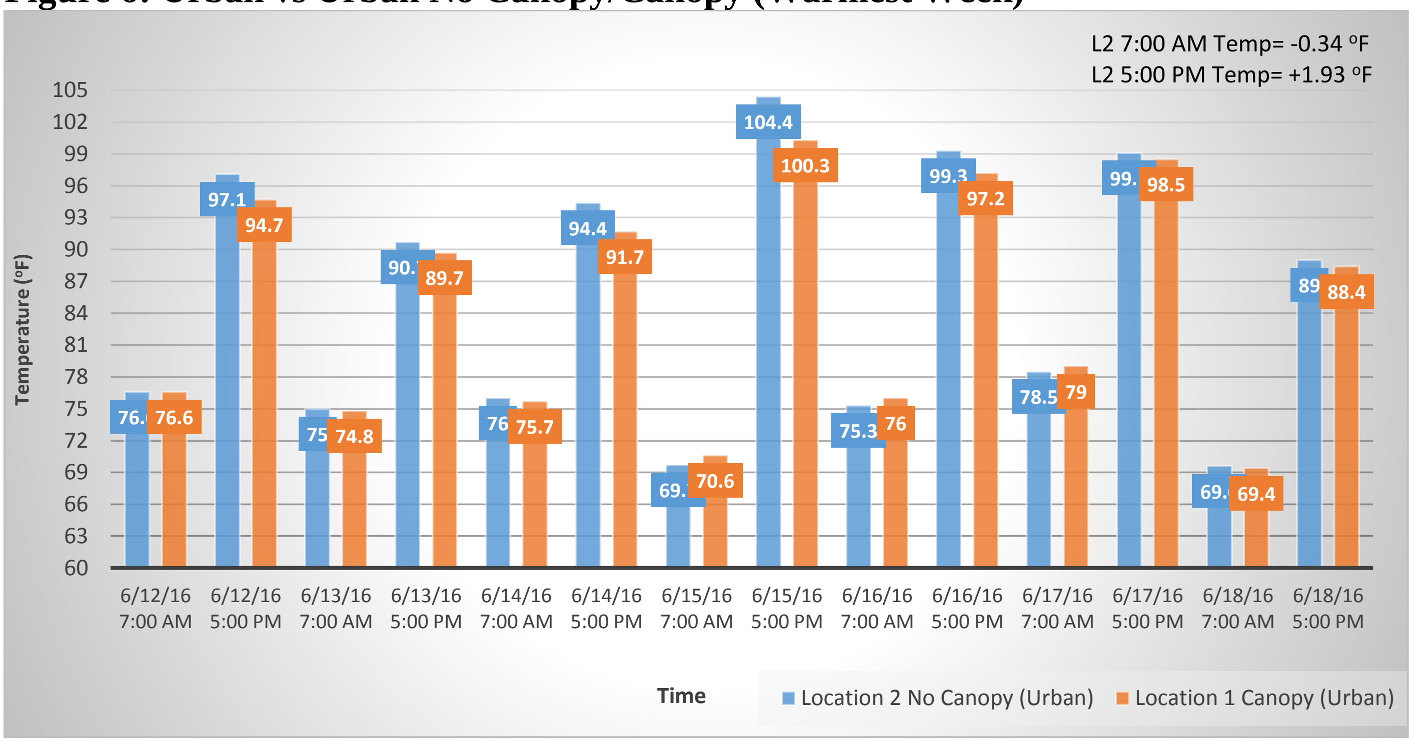

Figure 7: Urban vs Urban No Canopy/Canopy (Coldest Week)

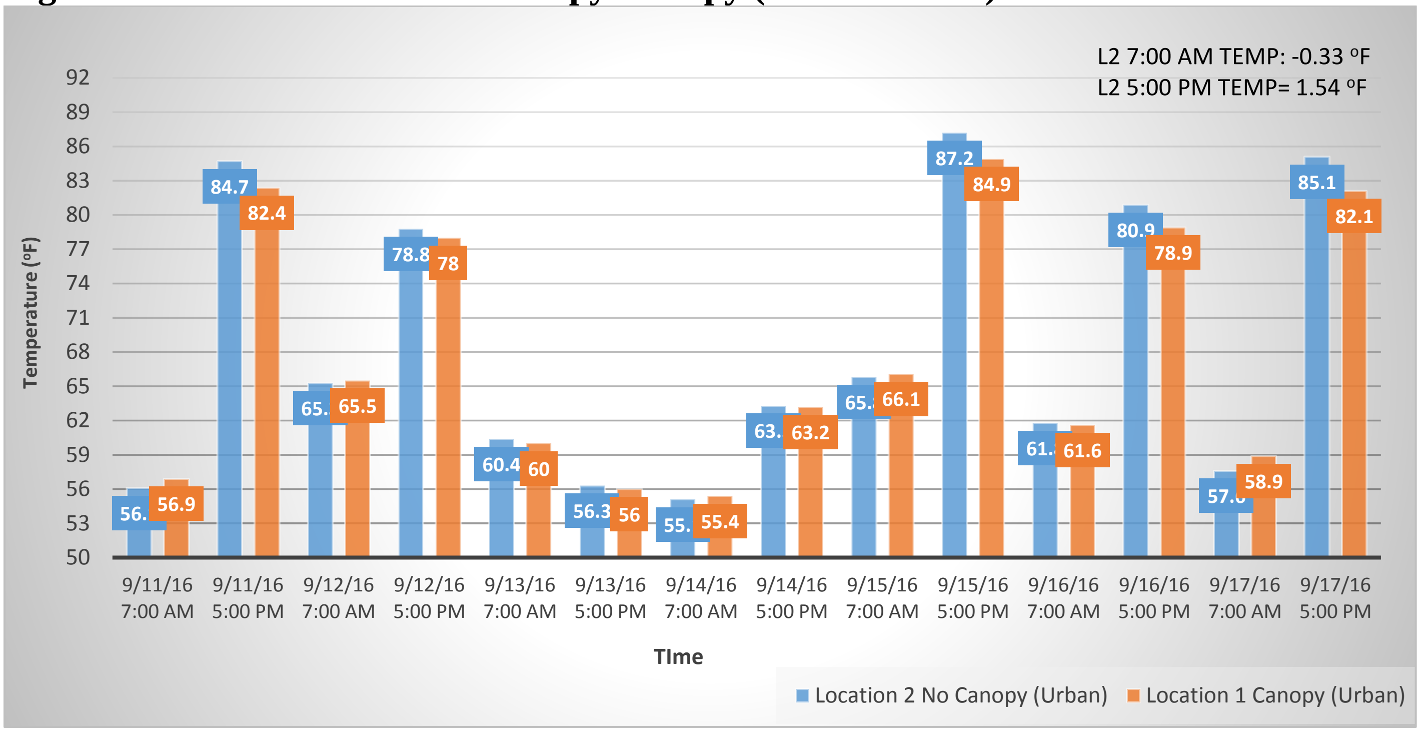

Figure 8. Urban vs Rural No Canopy Temperatures (Coldest Week & Removal of Outliers)

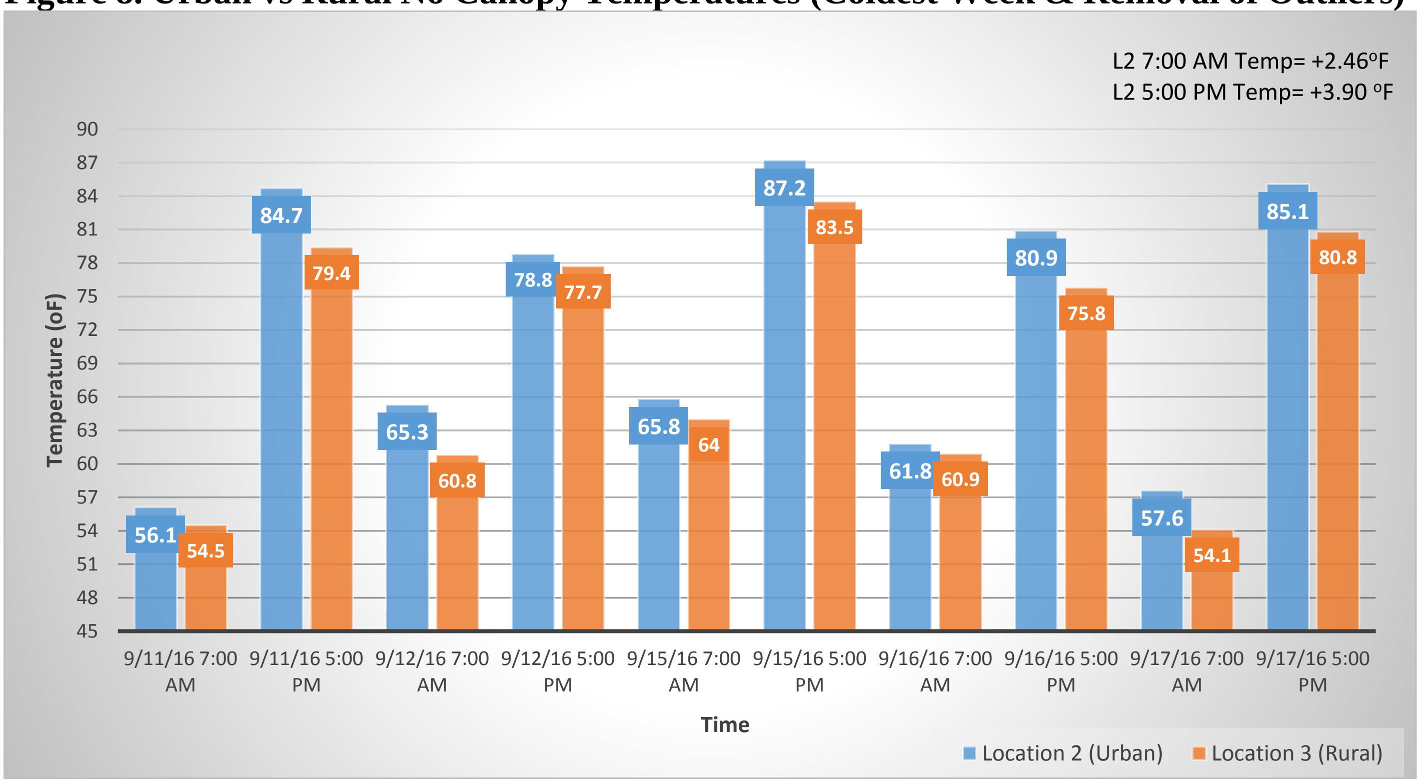

Figure 9: Urban vs Rural Canopy Temperatures (Coldest Week & Removal of Outliers)

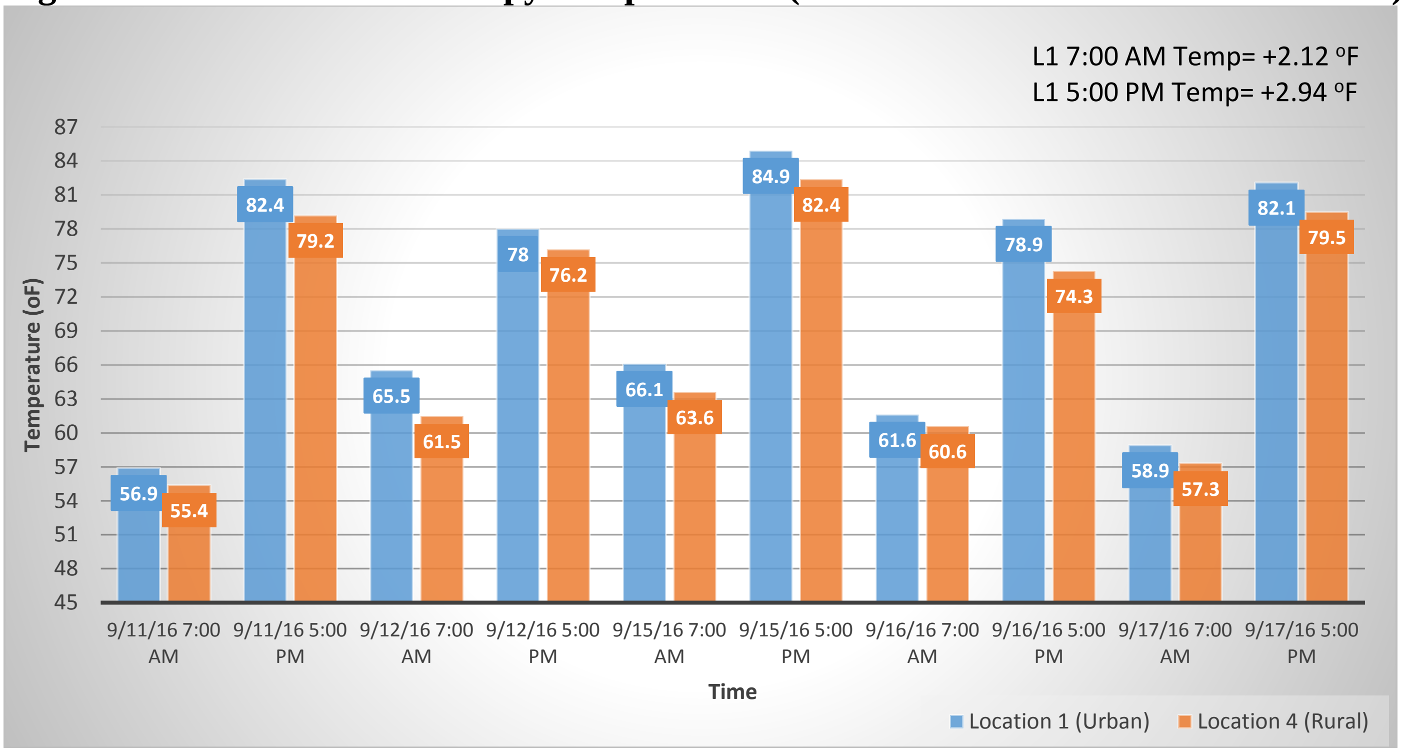

Figure 10. Urban vs Urban Canopy/No Canopy Temperatures (Coldest Week & Removal of Outliers)

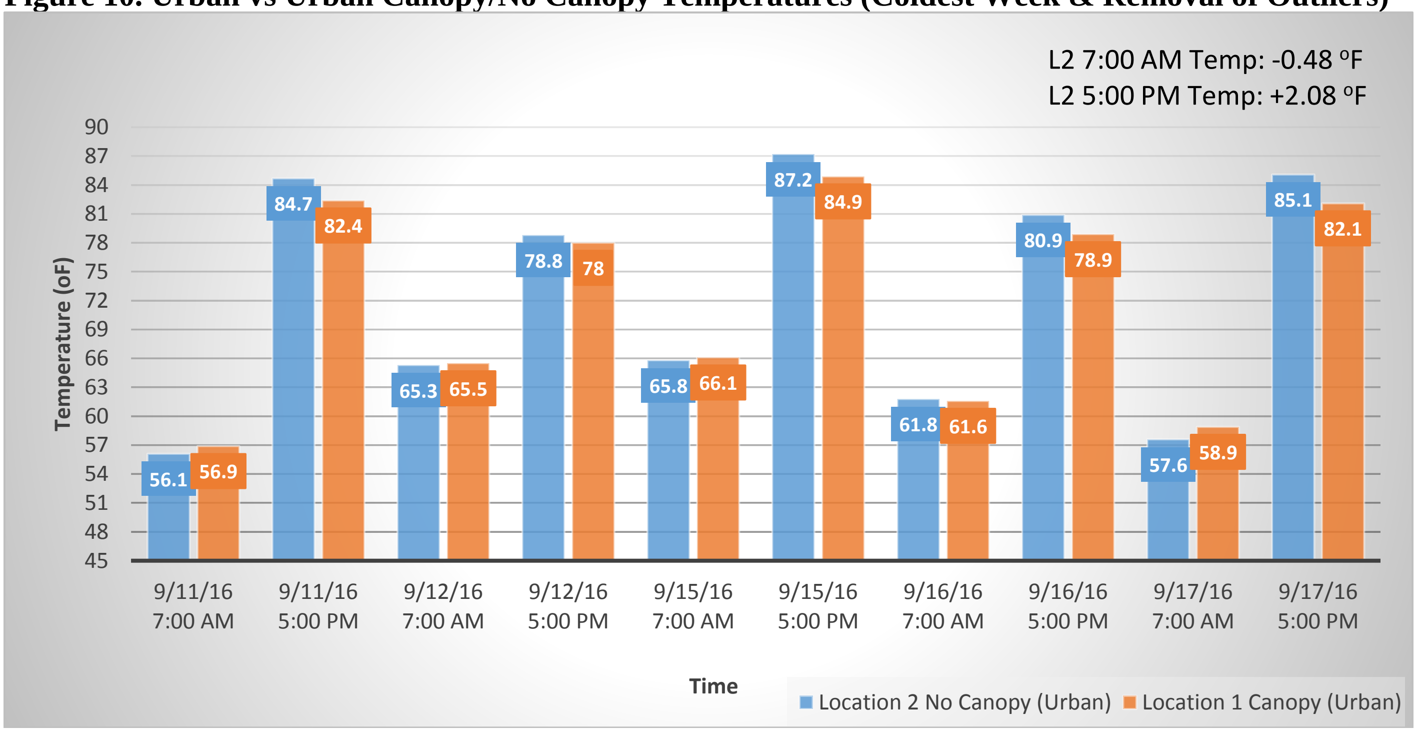

Table 1: Average 7:00 AM and 5:00 PM Temperatures

	7:00 AM Temperatures (ºF)	5:00 PM Temperatures (ºF)
Location 1 (Urban + Canopy)	69.74	84.98
Location 2 (Urban + No Canopy)	68.25	86.90
Location 3 (Rural + No Canopy)	66.27	82.66
Location 4 (Rural + Canopy)	66.41	81.81